

# The Deep Ultra-Violet Free Electron Laser (DUV-FEL) at Brookhaven National Laboratory

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## ABSTRACT

Brookhaven National Laboratory has established an initiative in FEL science and technology development which includes the Deep Ultra-Violet Free Electron Laser (DUV-FEL) experiment. It is configured as a sub-harmonically seeded High Gain Harmonic Generator (HGHG) to improve coherence and pulse control as contrasted with other schemes that start up from noise. In its initial configuration the DUV-FEL will allow operation at wavelengths down to 200 nm at pulse lengths below a picosecond. The DUV-FEL will be used as a test-bed for experiments to utilize the UV radiation it produces, and serve as model for extending its principles to much shorter wavelengths (x-rays).

**Keywords:** Free Electron Laser, High Gain Harmonic Generation, sub-harmonically seeded FEL

## INTRODUCTION

Accelerator based sources of light, have become powerful tools for research across many disciplines including the biomedical sciences. The spectrum of radiation from synchrotron storage rings extends from the far infrared well into the X-ray region. The developers of these machines continue to work to find new ways to add to their utility. One promising avenue of development is in the area of Free Electron Lasers (FEL's). These are essentially insertion device based synchrotron sources that have been enhanced by manipulation of the electrons passing through them into 'micro-bunched' beams. In the appropriate reference frame, light at wavelengths long compared to the microbunch size are emitted coherently. Qualitatively the microbunch looks like a single particle with a very large charge. Since the emitted radiation power scales as the square of the charge, the beam has higher power than if each electron emitted independently. This is an extreme simplification of the physics of FEL's which has a vast literature of its own. Much effort is being devoted to making this process work at ever-shorter wavelengths.

Until recently, all working FEL's were based on oscillator configurations where some of the radiation emitted by the FEL is coupled with subsequent electrons to enhance the microbunching effect. There are many research laboratories based on devices of this type from the far IR up to the visible and near UV[1] and the TJNAF FEL [2] has demonstrated multi-kilowatt level power in the IR. Reliable shorter wavelength (UV to X-ray) operation in oscillators has thus far been elusive, primarily due to the paucity of efficient mirrors for the cavity, and to some extent because of the relatively low peak electron beam power available. This has lead to the development of 'single-pass' FEL designs that take advantage of emerging high brightness electron beam technology that provides enough beam power that the microbunching can be produced and amplified in a single transit through a long undulator.

The most prevalent of these approaches is known as Self Amplified Spontaneous Emission or SASE. The spontaneous synchrotron radiation at the beginning of the undulator couples with the electrons as they pass through the undulator together producing the required microbunch structure. This process, which is also known as 'start-up from noise', has spectral characteristics that vary somewhat from one shot to the next, which can be exaggerated by variations in electron beam properties. These include the pulse length, electron beam energy and peak current, which are manifested in the FEL radiation as variations in light bandwidth, central wavelength and pulse energy. Several projects have been initiated to study these characteristics in detail and extend them to shorter wavelengths.

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At press time the APS Low Energy Undulator Test Line [3] has operated in the visible, and the DESY Tesla Test Facility FEL [3] has operated below 100 nm. A multi-laboratory collaboration known as the Linac Coherent Light Source (LCLS) [5] based at SLAC is aimed at exploring SASE FEL characteristics at and below 1.5 nm wavelengths. All of these projects are interested in the stability of the SASE FEL output and are considering alternative means of controlling the microbunching process by optical seeding of the electron beam. At BNL, we have been developing an approach based on laser seeding and high gain harmonic generation in the electron beam for some time [6].

The project described in this paper, the Deep Ultra-Violet Free Electron Laser (DUV-FEL) experiment, embodies the key elements of this strategy for the production of short wavelength FEL radiation. The technical approach and the experiment were developed in collaboration with potential users of the FEL light; control of the light and its utilization was strongly emphasized. It is a single pass device to avoid the wavelength limitations imposed by oscillator optics. It is configured as a sub-harmonically seeded High Gain Harmonic Generator (HGHG) to improve coherence and pulse control.

In this process UV light from a solid state laser (Titanium:Sapphire with conventional harmonic generation) is used to illuminate a photocathode in an RF electron gun. This generates an intense electron bunch that is accelerated by an electron linac. The electrons then pass through a short magnetic wiggler where they are coupled with light split off from the gun laser. The resulting energy modulation is then converted to spatial modulation (micro-bunching) in a dispersive section. A longer wiggler is then used to generate FEL radiation at harmonics of the initial seed laser. This process produces radiation with optical properties and stability that are controlled by the original seed laser (pulse length, bandwidth, coherence). This approach has recently been successfully demonstrated at BNL in the IR region, converting 10 micron wavelength seed radiation to 5 micron wavelength FEL radiation[7]. In its initial configuration the DUV-FEL will allow operation at wavelengths down to 200 nm at pulse lengths below a picosecond. Planned enhancements can extend this performance to wavelengths the order of 50 nm and pulse lengths as short as 10 femtoseconds.

## FACILITY DESCRIPTION

A considerable portion of the hardware required for assembling the DUV-FEL was recovered from earlier programs to keep the cost of the experiment down [8]. The linac was originally an injector for a compact storage ring project for soft x-ray lithography. With four SLAC type S-band structures powered by three 45 MW peak power klystrons, it is capable of producing electron energies of up to 210 MeV. Another 'surplus' component is the 10 meter long amplifier wiggler. Originally built for an Army supported FEL program, the NISUS<sup>†</sup> wiggler was transferred to BNL for the DUV-FEL. Substantial effort has gone into preparing these components for use in a single pass FEL.

The linac has been reconfigured with the addition of a photocathode electron gun [9] and a magnetic pulse compressor. The amplifier wiggler had been constructed several years ago and had no diagnostics. It has recently been magnetically re-measured and shimmed to the precision required for the DUV-FEL. Pop-in diagnostics have also been developed to allow the observation of the electron and photon beam properties as they propagate through the wiggler. The vacuum system has also been redesigned and is being installed. The energy modulation wiggler and dispersive section will be taken from the High Gain Harmonic Generation experiment at the BNL Accelerator Test Facility and installed on the DUV-FEL.

The laser system is based on a commercially available Ti:Sapp oscillator and regenerative amplifier that can be locked to the linac timing system RF drive clock at 81.6 MHz[10]. The laser can produce sub-ps pulses of up to 25 mJ of IR output that can be split off to different parts of the facility. Part of the laser power is used in long pulse (ps) BBO frequency tripler that generates the 266 nm light required to stimulate emission from the photocathode of the gun. The remaining available power will be used for optical diagnostics, seeding the FEL, and in pump-probe experiments with the FEL light. The configuration of the facility is shown in figure 1.

The pulse repetition rate of the DUV-FEL is 10 Hz, limited by the RF power system. The current linac energy also limits the FEL fundamental output wavelength to about 200 nm. An energy upgrade of the linac is being planned that would decrease the shortest possible wavelength to around 50 nm.

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<sup>†</sup> Near Infrared Scalable Undulator System

## PROSPECTS

One way to view the DUV-FEL is essentially as a harmonic generation and amplification system for a solid-state laser. Whatever you can produce in the laser can in principle be carried through to the FEL output. This includes its stability as well as programmed pulse formats that can be used to make the FEL a chirped pulse amplification system, potentially yielding pulses shorter than 10 femtoseconds at wavelengths below 100 nm with energies up to a milli-Joule[11]. These properties should prove valuable to experimental users of the DUV-FEL.

The other obvious feature of the facility is that pump-probe multicolor experiments should be readily possible with excellent timing jitter if the alternate colors can be derived from the gun or seed laser. It should be noted that the tuning agility of the FEL depends on the tuning of the seed laser. The bandwidth of the Ti:Sapp is sufficient for small tuning ranges with relative ease, but broadly tunable operation will depend on enhancing its capabilities over the present system.

At present (early 2000), linac commissioning is under way. The first SASE commissioning is planned for late 2000 with the first HGHG operation presently scheduled for mid 2001.

## ACKNOWLEDGEMENT

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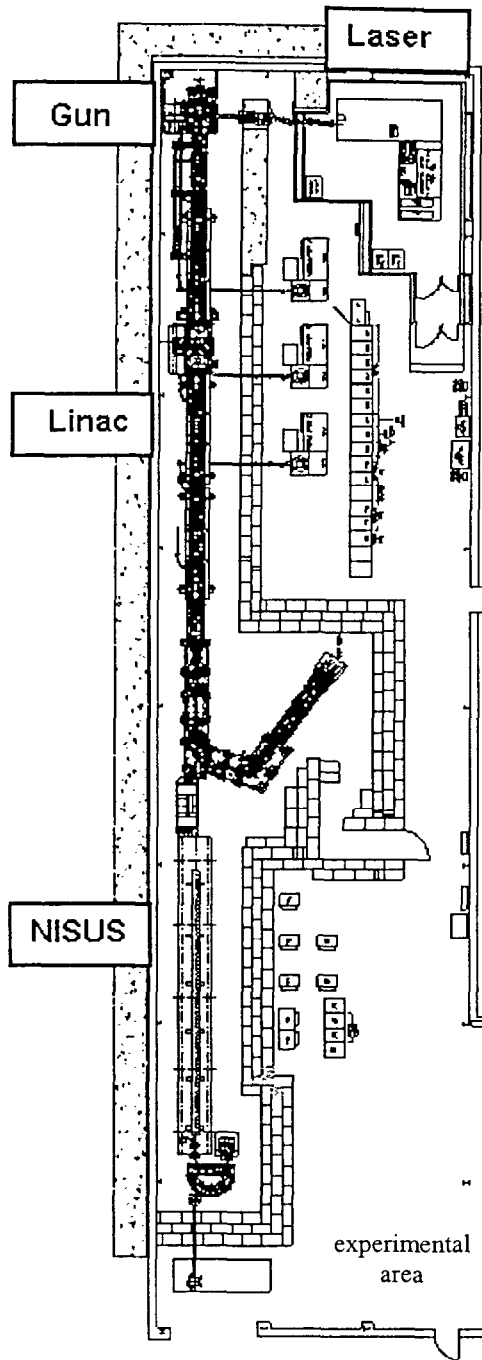


Figure 1 DUV-FEL Facility Layout. The major components are labeled with boxes next to them including the Laser Room (upper right) housing the Ti:Sapp laser, the photocathode gun (upper left), the linac with four sections and a pulse compressor followed by the NISUS amplifier wiggler at the bottom left. The NISUS wiggler is 10 m long.